say that that opinion no longer prevails, and among the requirements hereafter of a well-appointed establishment will be a properly constructed storm cave.

THE FORCE OF A TORNADO.[1]

By B. F. GROAT, Instructor in Mechanics, School of Mines, University of Minnesota. Dated, Minneapolis, July 24, 1899.

About forty hours after the recent tornado of June 12, at New Richmond, Wis., the writer and Mr. Peter Christianson, also of the University of Minnesota, visited the scene of the disaster.

At Boardman, Wis., about five miles from New Richmond, on the line of the Chicago, St. Paul, and Omaha Railway, we were much interested in two railroad switch targets, the rods of which, apparently owing to the great wind pressure on the surface of the targets, had become bent at an angle which from the train carrying us by we estimated at from 30° to 40° from the vertical. We endeavored to secure these rods from the railroad company in order that we might test the tensile strength of the rods and measure the angle of bending by which we might arrive at the average wind pressure on the vanes, but before Mr. W. A. Scott, General Manager of the railroad could get word to his men, considerable time having been unavoidably lost, the rods had been straightened Mr. Scott, however, very kindly furnished us with the most important dimensions of the targets, from which we have made a calculation that we think may interest the Weather Bureau; at least we believed others would like to know that two rods of the dimensions shown on the accompanying sketch (omitted) had been bent, as we suppose, by the force of the wind.

The exposure of the switch target to the wind is shown by an accompanying sketch (omitted.) A round vertical iron rod, $1\frac{3}{8}$ inch thick, supports vertically a feather-shaped iron plate that is 30 inches long and 13 inches broad.

The following is a brief outline of what we observed and our calculation: The two targets were apparently struck nearly normal to their surfaces by the wind. We had no opportunity to make a survey of the ground, although as we passed by we saw no evidence that the targets had been struck by flying débris of any consequence, but, of course, there is a chance that this may have been the case. As we could not learn the exact value of the angle of bend, we did not think the data sufficient to warrant a test of the tensile strength of the rods, but merely assumed a probable value, and from that and the dimensions of the target, calculated the average pressure per square foot of surface of the vane necessary to bring the bending moment of the rod to the point of straining.

The center of gravity of the surface exposed to the wind is about 36 inches along the central line of the rod above the bend. The area of the target, including that portion of rod above bend, is about 343 square inches. The rod at bend is $1\frac{3}{8}$ inches in diameter.

Assuming that the rod has a tensile strength of 30,000 pounds per square inch at elastic limit, which serves approximately either for wrought iron or soft steel, it is easy to show by the ordinary rules of mechanics, that the average pressure must have been at least 90 pounds per square foot of area normal to the wind, provided our assumptions are correct. If we use for the relation between pressure and velocity the formula $P = 0.005\,V^2$, we arrive at 134 miles per hour. Of course, to bend the rods to the angle mentioned would require considerable more pressure, but probably not enough to render it improbable that the rods were bent by the unaided force of the wind, especially when it is remembered that the tensile strength may be less than assumed. See line 16 from top of page 54, "Report of Board of Engineer Officers as to the maximum span practicable for suspension bridges," published by the War Department for a similar calculation in connection with the tornado that crossed the Champ de Mars.

[1] In submitting the accompanying article, Mr. B. F. Groat desires that attention be called to the fact that there is a possibility that the switch targets mentioned by him were struck by some heavy piece of flying material and not bent by the force of the wind only. On this point, he says he could not secure absolute evidence, but, from all that could be learned, he was led to believe that the targets were bent by the unaided force of the wind. Mr. W. A. Scott, General Manager of the Chicago, St. Paul, Minneapolis, and Omaha Railway made every endeavor to secure all desired information, even ordering the targets and rods taken out and shipped to him by express, for which courtesy Mr. Groat desires to make full acknowledgement.—ED.

SUDDEN OSCILLATIONS IN LAKE LEVEL—PRESSURE WAVES.

By ALFRED J. HENRY, Chief of Division.

[Extract from Lake Chart, September, 1899.]

A so-called tidal wave swept southwestward over Chequamegon Bay on the morning of July 22, 1899. The water of the bay rose suddenly about 3 feet above the normal stage, flooding a number of docks in Ashland, Wis., at the head of the bay, and causing several mills to shut down temporarily. At 11:30 a. m., the water began to recede, and by 3 p. m. it was slightly below normal. A second rise occurred about 4 p. m., and minor oscillations were noticed until the waters assumed their normal level. The wind was from the south and the weather fair.

Sudden waves and swells in tranquil weather have been noted on the Great Lakes, and commented upon from the earliest historic times. These sudden oscillations have never been, so far as known, of sufficient amplitude to seriously injure a vessel on the open lake. They may easily, however, be the cause of considerable damage in narrow channels, and especially in harbors where the shore lines converge to a point, as in the case of Ashland, thereby greatly increasing the size and destructiveness of the wave.

In April, 1893, a somewhat similar wave swept over the southern portion of Lake Michigan, causing a rise of the water in the harbors of about 4 feet.[1] Considerable damage was done to vessels anchored in the Chicago River and ports along the southeastern shore of Lake Michigan. The question was then asked, can these waves or *seiches*, as they are sometimes called, be predicted a few hours in advance of their coming?

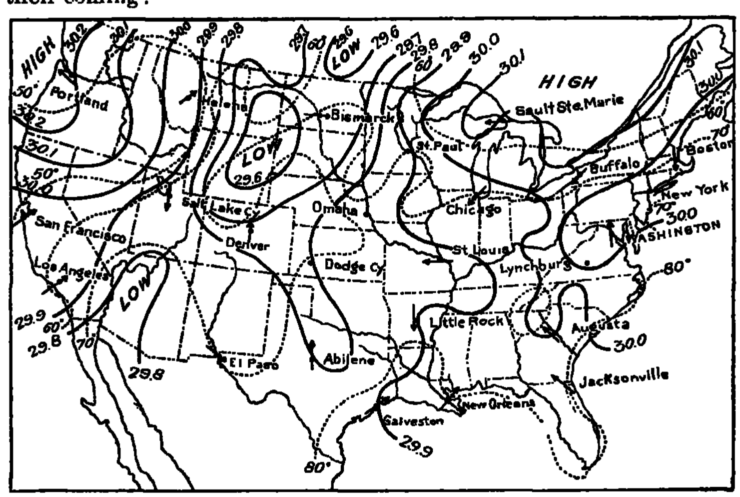

Fig. 4.—Pressure, temperature, and wind direction, 8 a. m. July 22, 1899 (75th meridian time).

The wave in Chequamegon Bay occurred at a time when the local weather conditions gave no sign of unusual disturbance. The daily weather map, however, shows that a storm whose influence extended over the region in question, was passing eastward north of the international boundary line. [See Fig. 4.] Light rain had fallen at Duluth and Port Arthur, but it is not known whether or not rain fell at Ashland.

The occurrence of sudden changes in the levels of lakes has been

[1] See Marine Record, April 13, 1893, American Meteorological Journal, October, 1893.

referred to several causes. Forel, who studied the oscillations in Lake Geneva with great assiduity, ascribes the occurrence of the seiche, a phenomenon not unlike the one under discussion, to (1) rapid local variations of atmospheric pressures; (2) the relaxation of the wind, which has heaped the lake waters up to one side; (3) a gust of wind striking the lake obliquely; (4) storms; (5) earthquakes.

* * * * * * *

Nearly thirty years ago Gen. (then major) C. B. Comstock, Engineer Corps, U. S. A., in charge of the survey of the northwestern lakes, was directed to make an examination of the seiches or unusual oscillations which occur on the lakes. General Comstock remarks on this point (Report of the Chief of Engineers, 1872, p. 1033):

"For a thorough examination of this subject, we need to have, on some one of the lakes where they occur, a sufficient number of self-registering tide gages, to record any unusual disturbance of the lake's surface which extended over any considerable area, and self-registering barometers at so many points that no local barometric disturbance could occur without being recorded. Then, if every unusual oscillation was coincident with or followed at a short interval a barometric disturbance at some part of the lake, the conclusion might be safely drawn that the latter was the cause of the former. No such thorough data exist or can be hoped for; but from an examination of unusual oscillations at Milwaukee and Marquette, it is seen that, as a rule, these oscillations occur with a low barometer, and in many cases with stormy weather, and thus suggest that the oscillations originate in barometric disturbance."

The above states the necessities of the case very clearly. Since it was written, many barographs have been installed at Weather Bureau offices in the Lake region and on vessels navigating the lakes, but, on the other hand, self-registering tide gages are lacking, except at a few places.

A number of barograph curves for the period noon of July 21 to noon of July 22, 1899, taken from instruments on vessels in harbor and on the open lake off the Apostles Islands, also at Weather Bureau stations to the westward of Duluth, are reproduced in Figs. 5 and 6. The barograph curves show a sudden and marked rise in pressure during the early morning of July 22. The amount of rise varied from about .008 to .015 inch. An increase of .015 inch in the pressure of the air would be equivalent to about 0.16 foot of water. This extra air pressure, if applied to the lake surface, as must have been the case, would tend to lower the water slightly in the region of greatest increase and to raise it in adjoining regions of lower pressure. It would also, it is believed, generate a small wave that would tend to move in all directions, but more especially toward regions of lower pressure, in the present case to the westward, since an area of high pressure covered the middle and eastern portions of the lake. A small lake wave thus generated might reasonably assume considerable proportions in approaching shoal water in a converging channel or bay. We should also suppose that the impulse of a wave so generated would be great enough to carry it to the nearest shores of the lake. In other words, an oscillation of greater or less amplitude should have been felt along the entire western shore from Ashland around by way of Duluth to, say, Port Arthur on the north. In the absence of self-registering tide gages it can not be stated whether such a wave actually occurred or not, but the fact that none was observed, except at Ashland, is of itself evidence that whatever wave was generated by the pressure changes, was not of sufficient magnitude to cause any serious damage. The size of the wave in Chequamegon Bay was due very largely to the relatively shoal water and the contour of the shore lines.

The actual oscillations of pressure over Chequamegon Bay are not known. The steamers *Zenith City* and *Merida*, whose barograms are given on Fig. 6, were probably the nearest to the point in question. The *Zenith City* was probably a little east-northeast of the larger islands of the Apostle Group in the fairway of vessels between Duluth and Keweenaw Point. The *Merida* was probably a little farther east. The increase of pressure occurred about 4 a. m., central time. If we assume that a wave in the lake resulted therefrom, it should have reached the entrance of Chequamegon Bay at about 4:45 a. m., central time, whereas it was reported by one observer as having reached there at 8:30 a. m., and by another at 10:00 a. m. The formula used in computing the velocity of the wave, as deduced by Merian[1] and simplified by Sir William Thomson, is as follows:

$$t = \frac{l}{\sqrt{(gh)}}, \text{ where}$$

t = time in minutes of a half oscillation of water, l the length of lake or other body of water, h its mean depth, and g gravity. The position of the steamer *Zenith City* was taken as 45 miles from the mouth of Chequamegon Bay and the mean depth of the lake as 240 feet. A complete vibration of the water, viz, from the steamer to the shore line east of Ashland and back to the starting point, would, according to the above formula, have occupied one hour and thirty minutes. We should note, however, that the pressure of the atmosphere did not remain stationary after the rise referred to, but rose and fell in a series of smaller undulations, and we must suppose that each pressure change was reproduced as a minute wave on the lake. We would have, therefore, not only the original wave, but a series of smaller waves, due to subsequent pressure changes, and a second series, moving in an opposite direction, due to reflection from the shore lines. While we think the high water in Chequamegon Bay was in some way connected with the pressure oscillations above referred to, there seems to be a considerable discrepancy between the time of the oscillations and the rise of the water. It is true the rate of propagation of a wave through the various channels of the Apostle Group would be less than on the open lake, but the retardation due to the islands would scarcely explain the discrepancy in time.

[1] Archives des Sciences Physiques et Naturales, Geneva, 1876, Vol. LVII, p. 278.

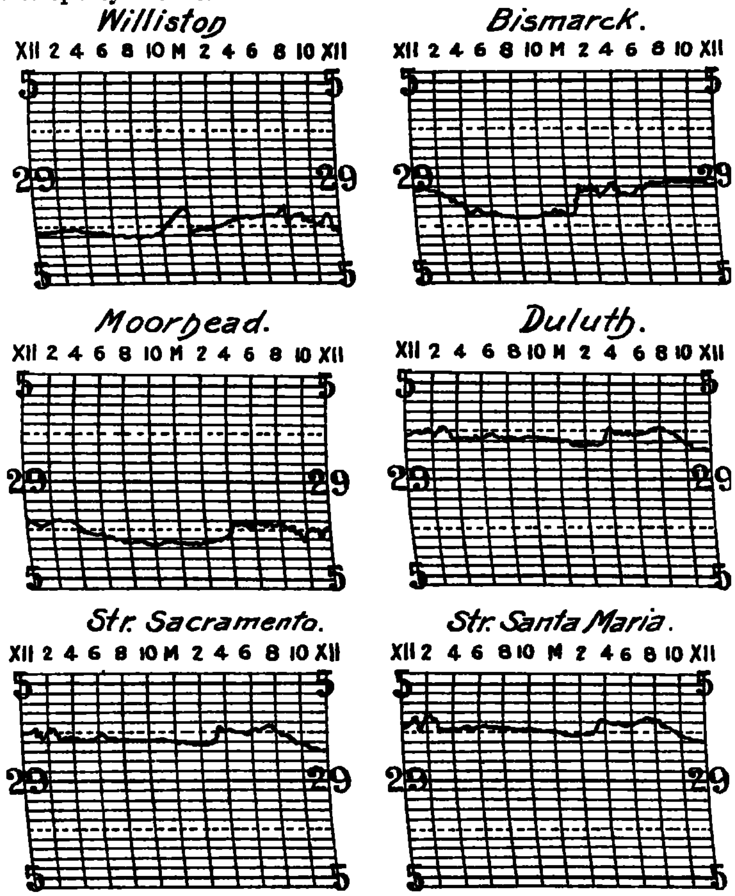

Fig. 5.—Barograms, noon July 21 to noon July 22, 1899.

The following letter from Maj. Clinton B. Sears, Corps of Engineers, U. S. A., is of particular interest in this connection:

"UNITED STATES ENGINEER OFFICE,
"519 PROVIDENCE BUILDING,
"*Duluth, Minn., August* 21, 1899.

"TO THE CHIEF OF THE UNITED STATES WEATHER BUREAU,
"DEPARTMENT OF AGRICULTURE,
"*Washington, D. C.*

"SIR: Replying to your letter of the 17th in the matter of the unusual perturbations of the water surface at Marquette, Mich. [on July 22, 1899], etc., I would say, that all the records this office has are the gage observations of that day. The gage readings are, as follows: 9 a. m., + 1.62; 1:00 p. m., + 1.20, and at 5:00 p. m., + 1.50. The mean for the three observations was + 1.44, which also happens to be the mean for the whole month.

"I would say in this connection, that it is not unusual for the water to rise and fall, in half an hour, as much as 18 to 20 inches in Chequamegon Bay and many other places on Lake Superior. Frequent and sudden rises and falls also occur in Marquette Harbor, and in many other landlocked bays and harbors they have been observed.

"Very respectfully,
(Signed) "CLINTON B. SEARS,
"*Major, Corps of Engineers, U. S. A.*"

From the above we should infer that there was considerable ebb and flow in the waters of the lake on the day in question. Pressure rose steadily at Marquette until about 9 a. m.; it fell rather abruptly .015 inch between 9:30 and 11 a. m., and remained about stationary during the remainder of the day. At Sault Ste. Marie, Mich., pressure began to fall sharply at 10:15 a. m., and continued falling until 12:30 p. m., the total fall being .012 inch.

There was a very noticeable earthquake shock in California on the date of the disturbance at Chequamegon Bay. Whether that fact shall be considered simply as a striking coincidence or whether there was any actual relation between the two phenomena, remains to be determined. We are of the opinion that a tilting of the lake bed by an earthquake shock would have produced a wave of much greater size and geographic extent than was noticed. Forel, in his study of the seiches on Lake Geneva, mentions the fact that while earthquakes frequently produce seiches, there were several sharp shocks that were not followed by seiches.

The theory that it was produced by pressure oscillations seems to be the most satisfactory, if the discrepancy in time could be accounted for. The wave of April 7, 1893, in the lower end of Lake Michigan, was accompanied or preceded by a sharp rise in pressure at several points. The barogram of the Chicago station on that date is shown on the bottom line of Fig. 6. According to Local Forecast Official H. C. Frankenfield the wave occurred between 1:30 and 1:45 a. m., April 7, which corresponds very closely with the time of the marked rise in pressure.

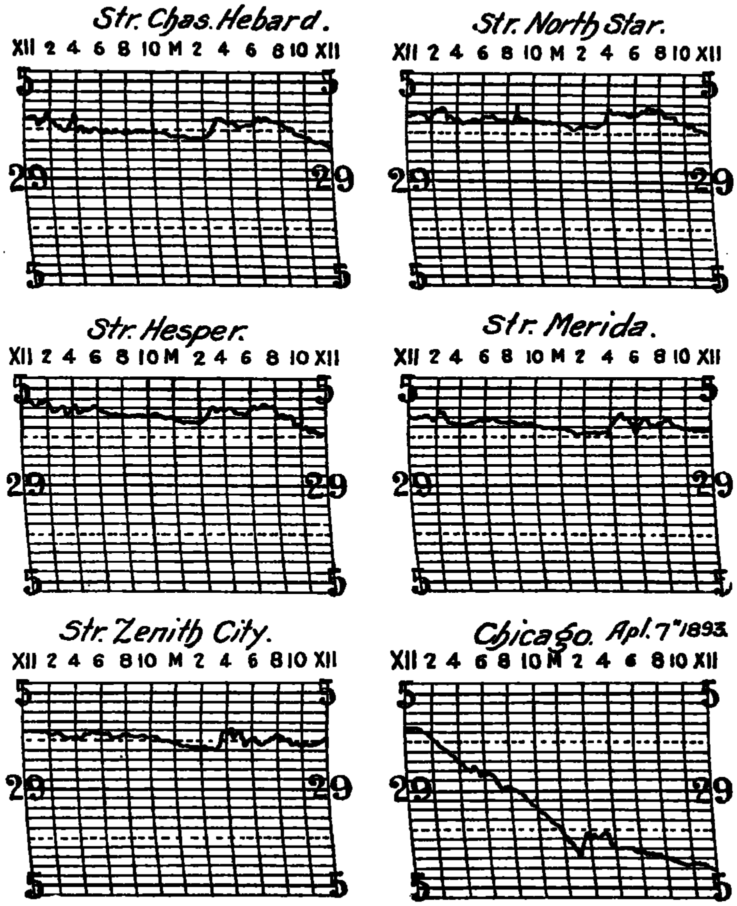

Fig. 6.—Barograms, noon July 21 to noon July 22, 1899.

NOTE.—The barograph clocks at the Weather Bureau stations in Williston and Bismarck, N. Dak., Moorhead and Duluth Minn., run on eastern standard time. Those on the vessels run on central standard time. The steamers *Sacramento*, *Santa Maria*, *Charles Hebard*, and *North Star* were in Duluth Harbor. The *Hesper* was at Superior and the *Merida* and *Zenith City* on the open lake east of the Apostle Islands.

The disturbance in atmospheric pressure on the western end of Lake Superior was local in a relative sense only. It did not extend as far east as Marquette, but, on the other hand, it was felt almost simultaneously from Duluth to the Apostle Islands, and we know not exactly how much farther in an east and west line; neither do we know its extent along a north and south line. It is a fortunate circumstance that pressure oscillations almost invariably extend over very considerable areas and shade off gradually from a maximum at some central point or axis to a minimum several hundred miles distant. There is, therefore, little danger of a large wave being created by such impulses.

It is important to note, in this connection, that the pressure oscillations on land and on vessels lying in the harbors were not so well marked as those on the two vessels in the open lake.

Looking at the results of a sudden increase of pressure from the standpoint of increased weight on the surface of the water, we are not a little surprised at the magnitude of the figures. An inch of mercury is equivalent to about 13.56 inches of water at the temperature of the water on Lake Superior. An increase in the air pressure corresponding to one-tenth of an inch of mercury would, therefore, be equivalent to an increase in the pressure on the lake surface corresponding to the weight of a layer of water 1.356 inches in depth. A cubic inch of water at a temperature of 62° F. and a pressure of 30 inches weighs 252 grains. The increase in weight over a square mile of water surface would therefore be $\frac{5,280 \times 5,280 \times 144 \times 1.356 \times 252}{7,000 \times 2,000} =$ in round numa little over 100,000 short tons.

TORNADO, HURRICANE, AND CYCLONE.

By HARVEY M. WATTS, Editor of the Philadelphia Press.

In pursuance of our policy of presenting matters in a popular way that may be useful to teachers in schools, we take pleasure in reprinting the following admirable article by Mr. Watts, who has long been an earnest advocate of honest fair play in the matter of meteorology and weather forecasts.—ED.

Owing to the confusion attendant upon the popular use of the words cyclone, hurricane, and tornado, as if they were interchangeable, it may be well, in these days of tornado and hurricane occurrence, to point out the radical differences between the three great classes of storm phenomena which are known to the United States. To begin with, the tornado is a purely local storm of great intensity and concentrated energy, whose main destructive effects are the result of the almost incredible velocity of its rotary winds that blow spirally into and about its vortex. Though terribly destructive to life and property, it is at the same time the smallest of local weather disturbances, being limited in duration, in the width of its path, and extent of its track. In one case it may last but a few minutes along a track a few hundred feet wide and a mile or so in length; in another it may persist for hours, its path several hundred yards in width and extending from 50 to 100 miles in length. Its forward motion on its track may vary from 15 to 30 to 60 miles an hour, but this speed is insignificant, compared with the velocity of the rotary winds which may have any speed from 100 to 500 miles an hour and over.

The rotary motion of the winds about the central core is the axis of the tornado and is usually made visible by the twisting movement of the funnel-shaped cloud, which is one of the most marked features of the typical tornado, and the actual existence of the rotary winds is made clear by the character of the destruction and the lay of the débris after the tornado has passed by. The tornado is in type nothing more than the familiar dust whirlwind common to city streets on warm or windy days, differing from it only in intensity, not in kind. Though the tornado under given conditions may form in any part of the United States east of the Rocky Mountains, it is of most frequent occurrence in the plains and rolling country of the Mississippi Valley, where topographical as well as meteorological conditions favor the formation and persistence of local whirlwinds of the tornadic type.

Aside from the destructive effects due to the rotary winds, there are in every tornado ascending currents of terrific velocity which rush up the core of the vortex, as a draught of hot air up the center of a tall chimney. As the rotary motion causes a movement of the winds away from the center of the core, the air here is so exhausted that it almost reaches the condition of a vacuum. The result of this is that in addition to the destructive effects of its rotary and ascending currents the tornado causes serious damage by reason of explosive effects, for if the center with its partial vacuum passes over a house in which the air is at ordinary atmospheric pressure, this air blows outward as if gunpowder had exploded within it. In this way some houses are destroyed which escape damage from the whirling winds.

Though not as destructive as the tornado, and hence second to it in importance in this respect in the classification of local storm phenomena, the thunderstorm is a much more extensive weather disturbance. It is not a storm disturbance rotating about a vertical axis, but moves across the country with a comparatively straight front, often many miles in extent, out from under which rushes the wind squall. In depth from front to rear the typical thunderstorm may reach from 5 to 15 miles and more. The destructive effects of a thunderstorm are due to the lightning, hail, the heavy rainfall, which sometimes approaches the character of a so-called cloudburst, and the high winds that make up the familiar outrushing thunder squall, which may occur before or after rain has begun to fall. The squall winds may reach a velocity of 60 miles an hour or so in gusts, and hence may do considerable damage, though the velocity is nothing compared with the rotary velocities of the tornadic winds.

Covering a large area, under favorable conditions, the thunderstorm may endure for hours, and in its track may cover a region from 100 to 250 miles in linear extent. Itself the result of unstable conditions of the atmosphere, it may develop within its sphere of influence secon-